STUDIES OF THE MAGNITUDES IN STAR CLUSTERS, IV. ON THE COLOR OF STARS IN THE GALACTIC CLOUDS SURROUNDING MESSIER 11

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The investigation of phenomena relating to brightness and color in the clusters that are located in rich regions of the sky necessitates a knowledge of certain properties of the neighboring stars. A catalog of the members of any cluster must inevitably include some stars extraneous to the group, and to a greater or less extent the colors and magnitudes of such objects will influence the interpretation of the results. For the globular clusters, particularly in high galactic latitude, the preponderance of cluster stars over those that chance to be included with them is such that no serious effect is to be feared. For the open clusters, however, and especially for those in the Milky Way, the number of background or foreground stars may easily exceed the number of physical members of the cluster, even at the center of the group. In these cases it becomes necessary to make a direct and special study of the extra-cluster stars in fields far enough removed from the cluster to be practically free of its outlying members, but not so distant that the field stars can not be considered representative of those that in projection appear commingled with the cluster.

A study of the colors in the open galactic system Messier 11 (N. G. C. 6705) has been completed with the compilation of a catalog of the magnitudes and colors of nearly five hundred stars. The cluster is situated in the constellation Scutum Sobieski, in one of the densest of the great star clouds of the Milky Way. Unlike the stars in Messier 67, in which all the fainter objects are yellow and red (and similar in most respects to the neighboring non-cluster stars), those in Messier 11 fall into all color classes, but with a distinct preference for the bluer types. The group is but four degrees from the mid-line of the Galaxy; Messier 67 is in galactic latitude $+34°$. To find whether the presence of blue faint stars in Messier 11 is a peculiarity of the cluster or is only a result of its low galactic latitude and its association with the star clouds, a special study in several neighboring fields was undertaken. This investigation bears directly on the relation of the cluster to the surrounding stellar masses, and also yields information regarding the nature of the galactic clouds themselves and the spectra and intrinsic luminosities of the numberless stars that compose them.

Nearly forty plates, made with the 60-inch reflector, have been used in the present work. In addition to the above-mentioned catalog of stars in and near the cluster, photographic and photovisual magnitudes of more than 300 stars in four other neighboring fields have been determined by comparisons with the cluster and checked by direct comparisons with the Polar Standards. Special care was taken to avoid

PERCENTAGE FREQUENCY OF COLORS IN GALACTIC CLOUD FIELDS

	COLOR CLASS											
	*b*0	*b*5	*a*0	*a*5	*f*0	*f*5	*g*0	*g*5	*k*0	*k*5	*m*0	*m*5
Field I	0	2	6	12	18	12	12	16	12	4	2	4
Field II	1	3	7	17	13	8	8	8	12	12	5	6*
Field III	0	2	17	29	10	10	10	8	4	8	4	0
Field IV	0	0	2	27	24	22	10	0	8	4	4	0
All fields	0.3	2	8	20	15	11	9	8	10	8	4	4†

* 2.5% have color indices greater than +2.00.

† 1.3% have color indices greater than +2.00.

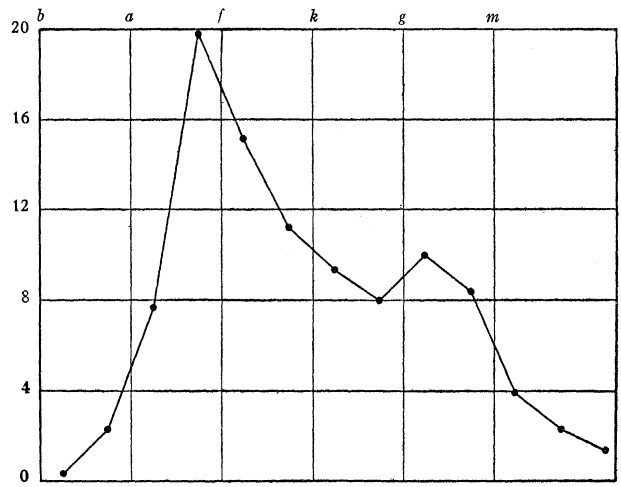

FIG. 1. FREQUENCY OF COLORS IN GALACTIC CLOUDS. ABSCISSAE ARE COLOR CLASSES; ORDINATES ARE PERCENTAGES.

the use of questionable photographs or of doubtful star images, and systematic errors of any importance are probably completely absent from the results. The average probable error of a color index varies in the different fields from a tenth to a twentieth of a magnitude.

The interval of photovisual magnitude investigated is from 11.0 to 15.5. The relative frequency of color class is given in the accompanying table for each field separately and for the four together. Figure 1

illustrates the combined results. The most important features are the great diversity of color index and the general resemblance of this frequency curve to that for the brighter stars in the immediate neighborhood of the sun.[1]

The full presentation of the material will appear in two forthcoming *Contributions from the Mount Wilson Solar Observatory*. Some of the conclusions to be drawn from the results may be summarized as follows:

1. Messier 11, in common with many other open clusters, does not differ greatly in the brightness and color of its stars from the non-condensed fields which surround it. Though its members without doubt form a distinct physical system, it is probably at approximately the same distance from the sun as the stars of corresponding color and apparent magnitude in the galactic cloud. In fact, the study of colors and magnitudes tends to confirm Barnard's inference, based on general appearances, that the cluster may be nothing more than a nucleus of the extensive surrounding stellar masses.[2] In this similarity to its environment, therefore, Messier 11 is vastly different from a globular cluster, such as Messier 13, which is apparently much more distant than the non-cluster stars in the same part of the sky.[3]

2. The distance of all the stars of Messier 11 is sensibly the same; hence apparent magnitudes represent relative absolute luminosities. Plotting the average color index against magnitude, as in figure 2, a striking progression of color with decreasing brightness is revealed. The neighboring stars, though showing much the same frequency of color class, are probably more scattered in space, and each interval of magnitude includes stars varying greatly in distance and of most diverse spectral types. The indefinite relation between magnitude and color index here observed is, therefore, not unexpected.

3. Accepting the present results as dependable and taking color class and spectral type as closely analogous, the presence of the small and negative color indices in the galactic clouds indicates either that the stars are at a great distance or that they are not similar in luminosity to the brighter stars near the sun. In the light of recent researches on the dispersion of absolute magnitudes of B and A-type stars, the first alternative is decidedly preferable. The parallax of a typical B-type star of apparent magnitude 13.5 would be about 0".0002, a value that may be taken as a first estimate of the distance of Messier 11. The *b*-class stars in the surrounding clouds are between magnitudes 13 and 15 and some are possibly fainter—suggesting still greater distances for parts of the stellar background.

4. Just as a wide range of color class and the presence of negative

color indices in the globular cluster Messier 13 indicated the absence of scattering of light in space,[4] the similar properties of the faint stars in Messier 11 and the galactic clouds show that in this direction also light is not appreciably diminished by scattering.

5. The present investigation contributes to the problem of the color of the faint stars, and consequently, if space absorption is accepted as ineffective, to the question of the extent and character of the galactic system. The increase of the minimum color index with decreasing brightness has been observed by Seares[5] for the north polar stars, galactic latitude +28°, by Hertzsprung[6] and Seares[7] in the open cluster

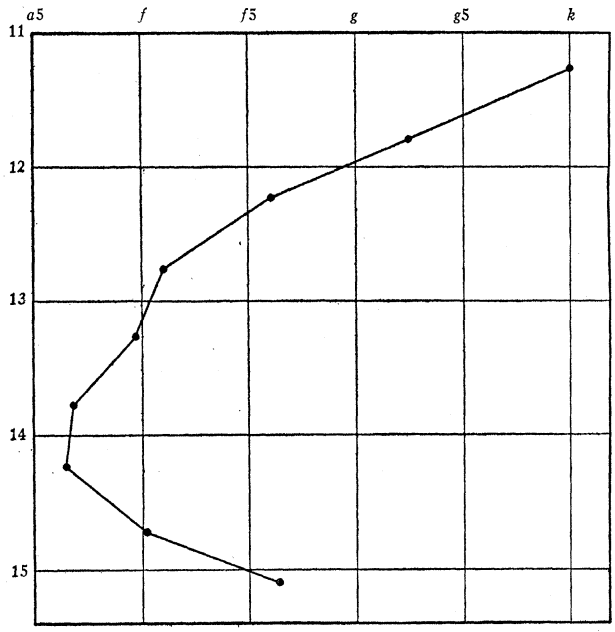

FIG. 2. RELATION BETWEEN COLOR AND LUMINOSITY IN MESSIER 11. ABSCISSAE ARE COLOR CLASSES; ORDINATES ARE APPARENT MAGNITUDES.

N. G. C. 1647, galactic latitude −15°, by the present writer in and around Messier 67,[8] galactic latitude +34°, and in the neighborhood of Messier 13, galactic latitude +40°. In none of these fields have very small or negative color indices appeared among the fainter stars;[9] and a definite, accessible limit to the galactic system was thus suggested, at least for the higher galactic latitudes. The first divergence from this tendency was found in the field of the variable star XX Cygni,[10] galactic latitude +13°, where 13th magnitude stars of color *b* were found, as well as a number of faint *a*'s. Similarly, faint blue stars have been recently observed by the writer in the region of the Perseus cluster,

galactic latitude $-3°$. With the addition of the data for Messier 11 and for the four neighboring fields, it appears that the redness of the faint stars will be found to depend, as might be expected, upon galactic latitude, and in the mid-galactic regions will vary with the density of the star clouds.

6. The presence of negative color indices for faint stars in the three widely separated galactic regions mentioned above shows that, if these stars are typical in absolute brightness, the dimensions of the galactic system in the plane of the Milky Way are many times greater than has been inferred from studies of variables and investigations of the motions and magnitudes of the brighter stars.

[1] For instance, see Parkhurst, Yerkes Actinometry, *Astroph. J., Chicago, Ill.*, **36**, 1912, (218, 225) and figure 5 on p. 56 of *Mt. Wilson Contrib.*, No. 116.

[2] *Berkeley, Univ. Cal. Pub., Lick Obs.* **11**, 1913, Plate 62.

[3] *Mt. Wilson Contrib.*, No. 116, 1915, (81 ff.).

[4] These PROCEEDINGS, **2**, 1916, (12–15).

[5] *Astroph. J., Chicago, Ill.*, **39**, 1914, (361–369); [*Mt. Wilson Contrib.*, No. 81].

[6] *Ibid.*, **42**, 1915, (92–119); [*Mt. Wilson Contrib.*, No. 100].

[7] *Ibid.*, **42**, 1915, (120–132); [*Mt. Wilson Contrib.*, No. 102].

[8] *Mt. Wilson Contrib.*, No. 117, 1916. The unpublished results for the fields near Messier 13 are provisional.

[9] In N. G. C. 1647 Hertzsprung (*loc. cit.*) finds one star of photographic magnitude 12.40 that is apparently of spectral type B.

[10] *Astroph. J., Chicago, Ill.*, **42**, 1915 (148–162); [*Mt. Wilson Contrib.*, No. 104].

THE COLOR OF THE STANDARD POLAR STARS DETERMINED BY THE METHOD OF EXPOSURE-RATIOS

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An earlier note in these PROCEEDINGS describes a method of measuring the color of a star which depends upon the ratio of the exposure times necessary for its blue and yellow light to produce images of the same size.[1] A comparison of the observed exposure-ratio with a curve derived by combining similar ratios for stars of known color affords a means of expressing the results in terms of color-index or color-class.

The method is expeditious, and, under favorable conditions, precise; it is entirely independent of stellar magnitudes, and hence avoids the systematic errors which so easily enter as a result of uncertainties in the magnitude scales or in their zero points. Moreover, the method is direct, in the sense that color is measured and not inferred from observations of spectral type. The results thus include that part of the color